



Integrated Design Center / Mission Design Laboratory

PACE 2012

Avionics

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N A S A G O D D A R D S P A C E F L I G H T C E N T E R





Subsystem Agenda

M i s s i o n D e s i g n L a b o r a t o r y

- Overview
- Block Diagram
- Subsystem Description
- Issues / Potential Risks / Future work
- Acronym List
- Backup Material





Executive Summary

Spacecraft Avionic System

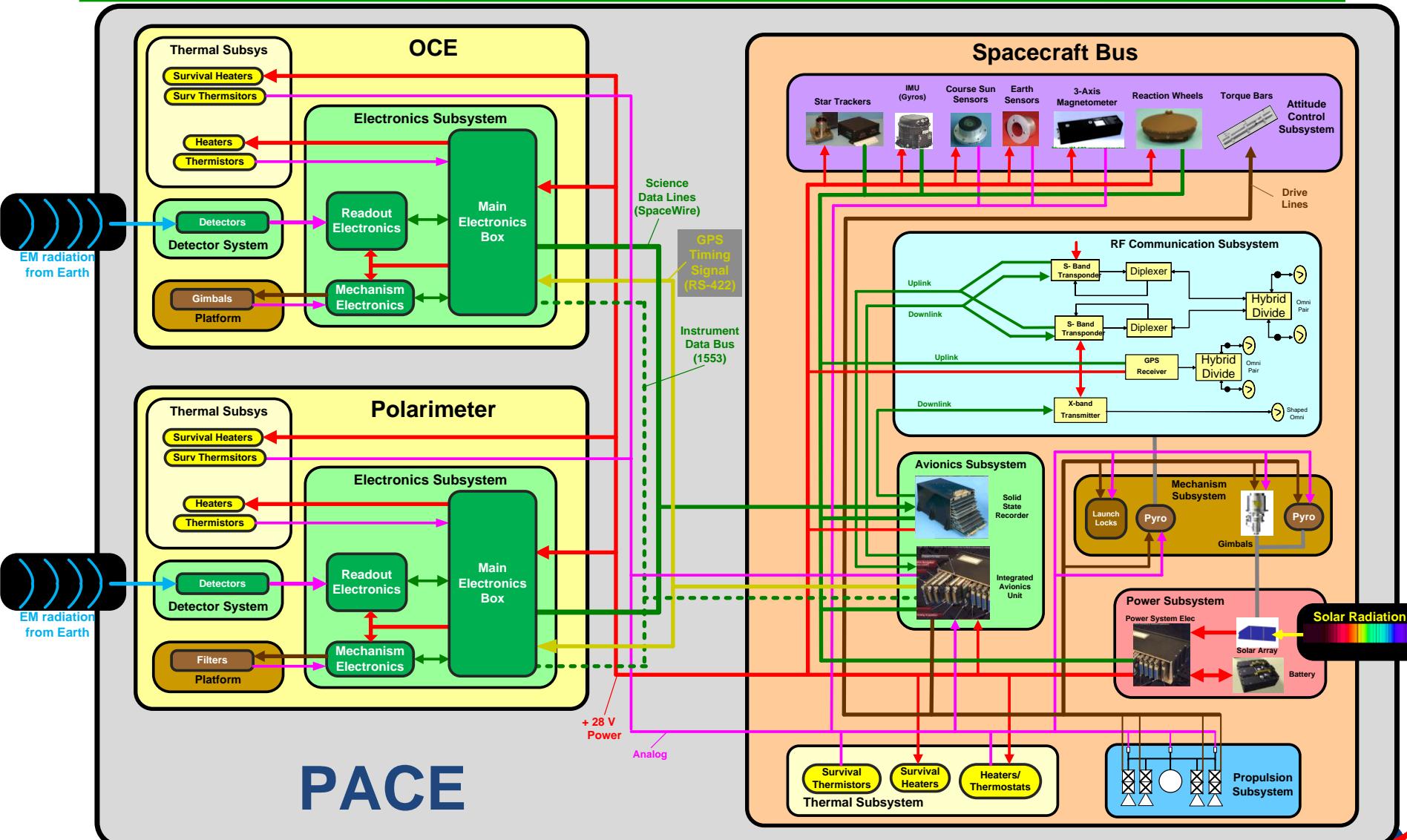
M I S S I O N D E S I G N L A B O R A T O R Y

Specification Categories	Integrated Avionics Unit (IAU)	Solid State Recorder (SSR)	Totals
Functional	<ul style="list-style-type: none">▪ C&DH: Data Processing, Digital & Analog I/O▪ ACS I/F, Control & Monitoring▪ Mechanism Deployment▪ Power Control & Monitoring▪ Thermal I/F, Control and Monitoring▪ Instrument I/F, Control & Monitoring▪ Science Data Acquisition, Storage & Playback	<ul style="list-style-type: none">▪ Required due to large data storage volume requirement	
Performance	<ul style="list-style-type: none">• 3-Axis Stabilized Algorithm Processing• Support 100+ Mbps Downlink Data Rate	<ul style="list-style-type: none">▪ 100+ Gbits Data Storage	
Fault Tolerance	Single Fault Tolerant (Internal design risk mitigation)	Internally Redundant with 1 spare memory card	
Avionic Units (cards)	1 unit (10 cards)	1 unit (6 cards)	2 units
Physical Unit Size	Width: 25 cm Depth: 19 cm Height: 10 cm	Width: 18 cm Depth: 25 cm Height: 11 cm	
Mass (total)	12 kg	12 kg	24 kg
Average Power:	59 W	24 W	83 W
Peak Power:	68 W	24 W	92 W
Technical Risk	Small	Small	Small
Development Risk	Small	Small	Small





PACE Electrical System Schematic Diagram



Subsystem Overview

M I S S I O N D E S I G N L A B O R A T O R Y

- **Class-C mission – assumptions**

- Selective redundancy/mitigation at a low level
- Critical components may have built-in redundancy (e.g., SSR)

- **Integrated Avionic Unit (IAU)**

- Selective redundancy/mitigation at the board design level
- Commercial products to be purchased if possible (COTS)
- Dedicated cards designed at GSFC if needed

- **Solid State Recorder (SSR)**

- Built-in redundancy
- Have an X-Band transmitter card for high speed COMMS

- **General**

- GPS timing and position data available, to be distributed via dedicated bus
- Safehold scheme/algorithm on a dedicated implementation to account for specific instrument safety/survival requirements
- Maximum downlink data rate limited by current high-TRL hardware/software options

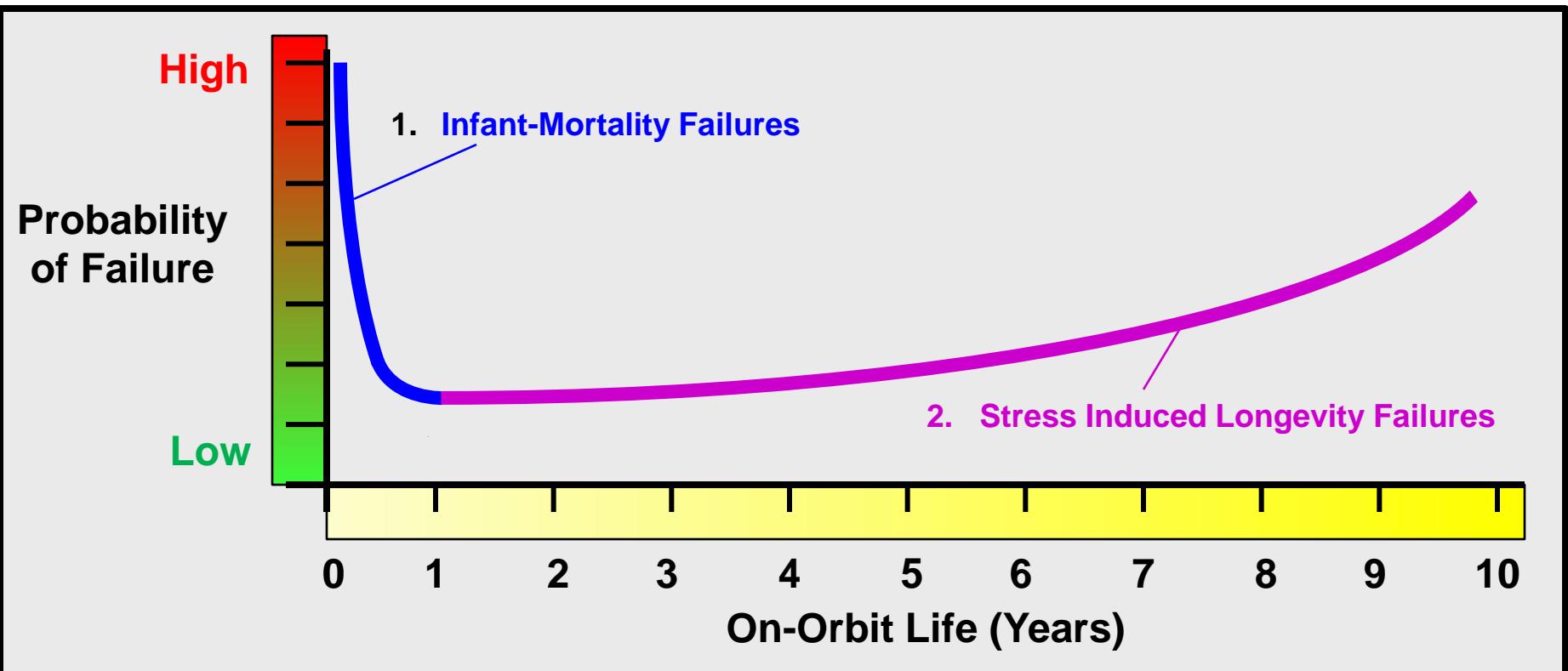


Avionic System Probability of Failure Curve

M I S S I O N D E S I G N L A B O R A T O R Y

Avionics/Electronics failures fall into two categories:

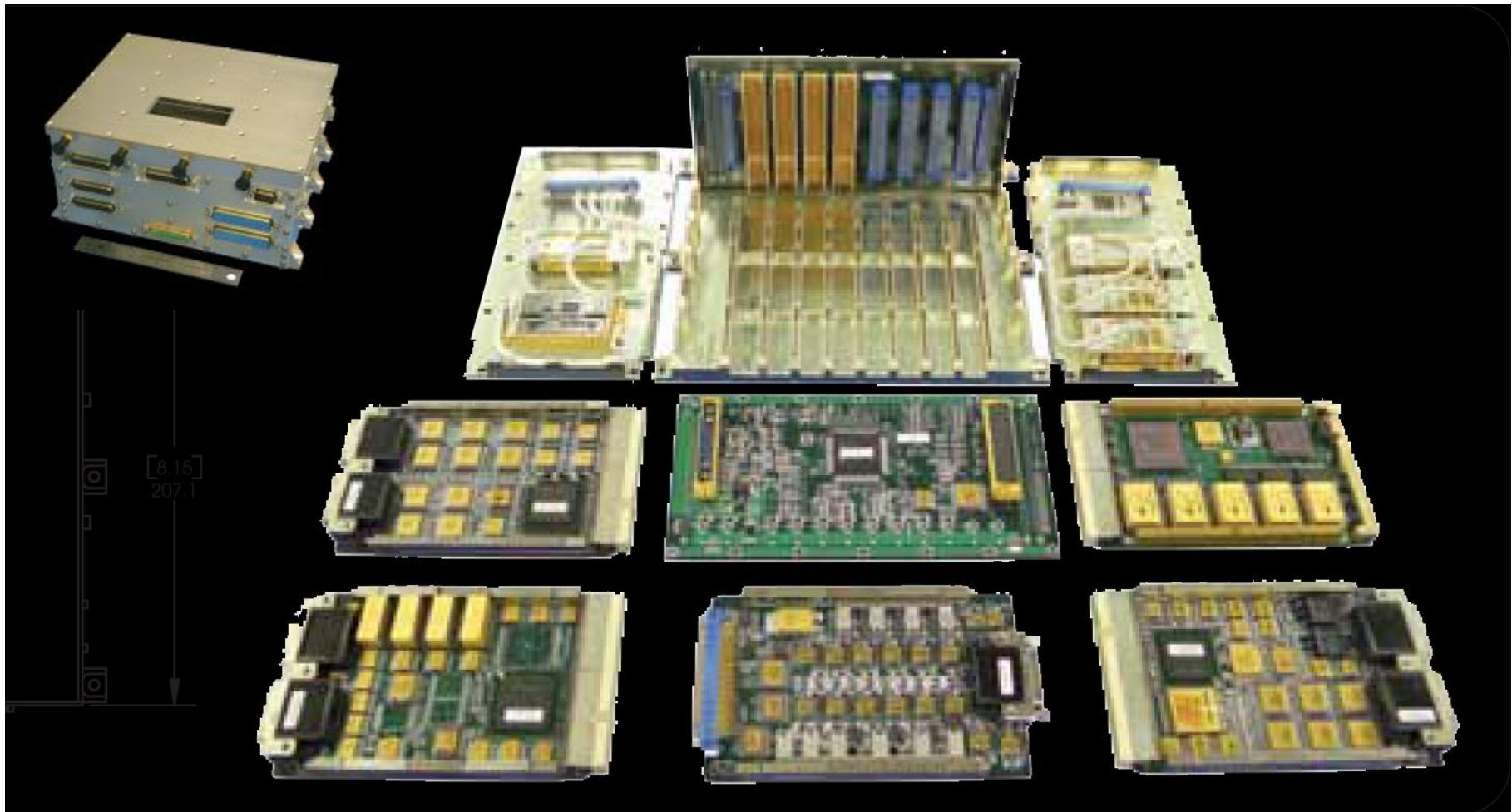
1. Infant-Mortality Failures
2. Stress Induced Longevity Failures



Probable Avionic System Implementation Products:

#1a. Broad Reach Integrated Avionics Unit (IAU)

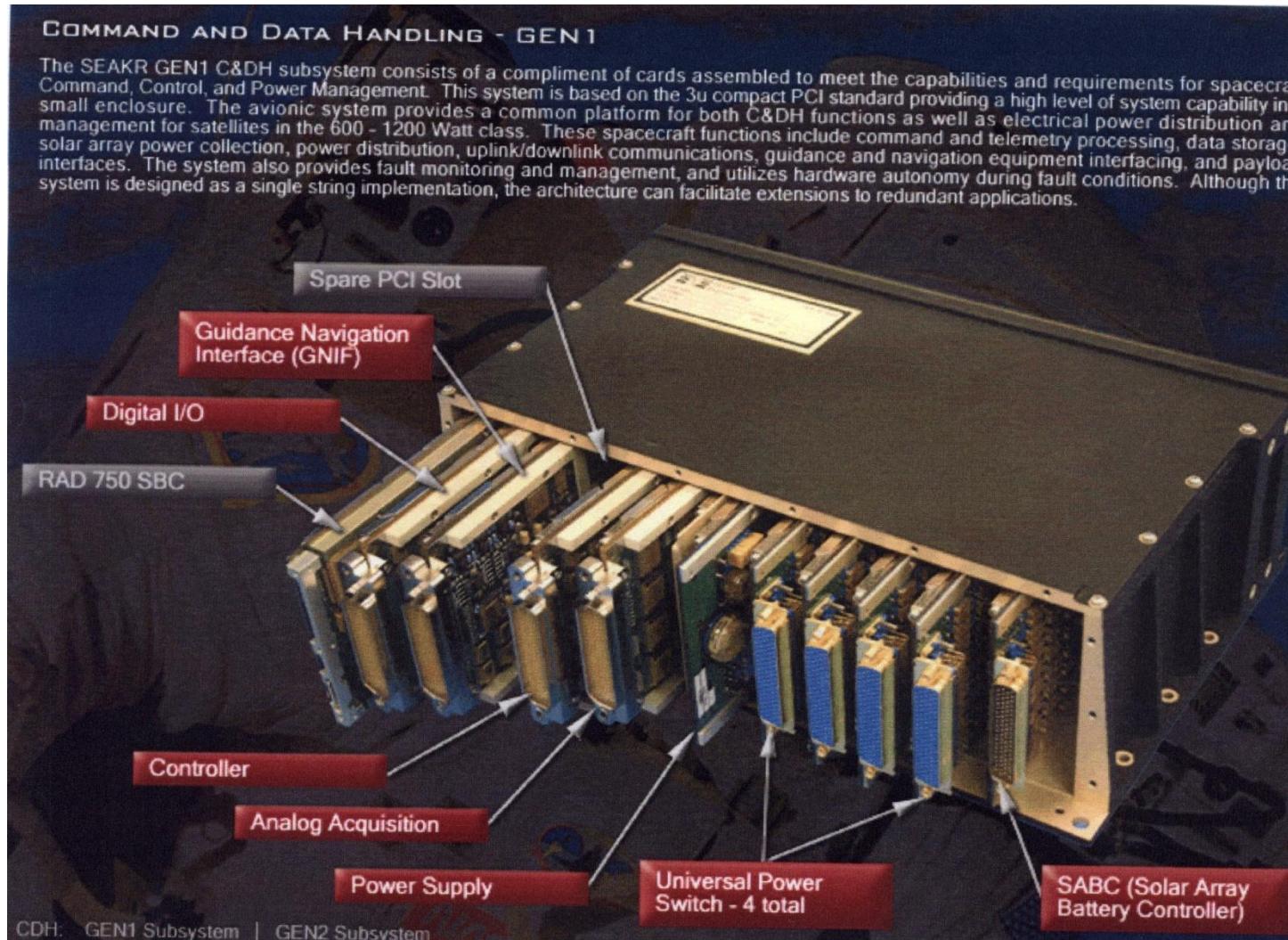
M I S S I O N D E S I G N L A B O R A T O R Y



Probable Avionic System Implementation Products:

#1b. SEAKR GEN1 Integrated Avionics Unit (IAU)

M i s s i o n D e s i g n L a b o r a t o r y

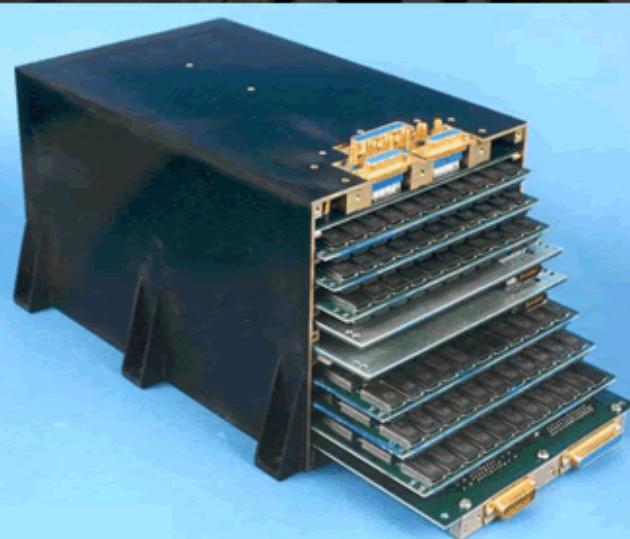


Probable Avionic System Implementation Products: #2. SEAKR P9 Solid State Recorder (SSR)

M I S S I O N D E S I G N L A B O R A T O R Y

SSR - P9

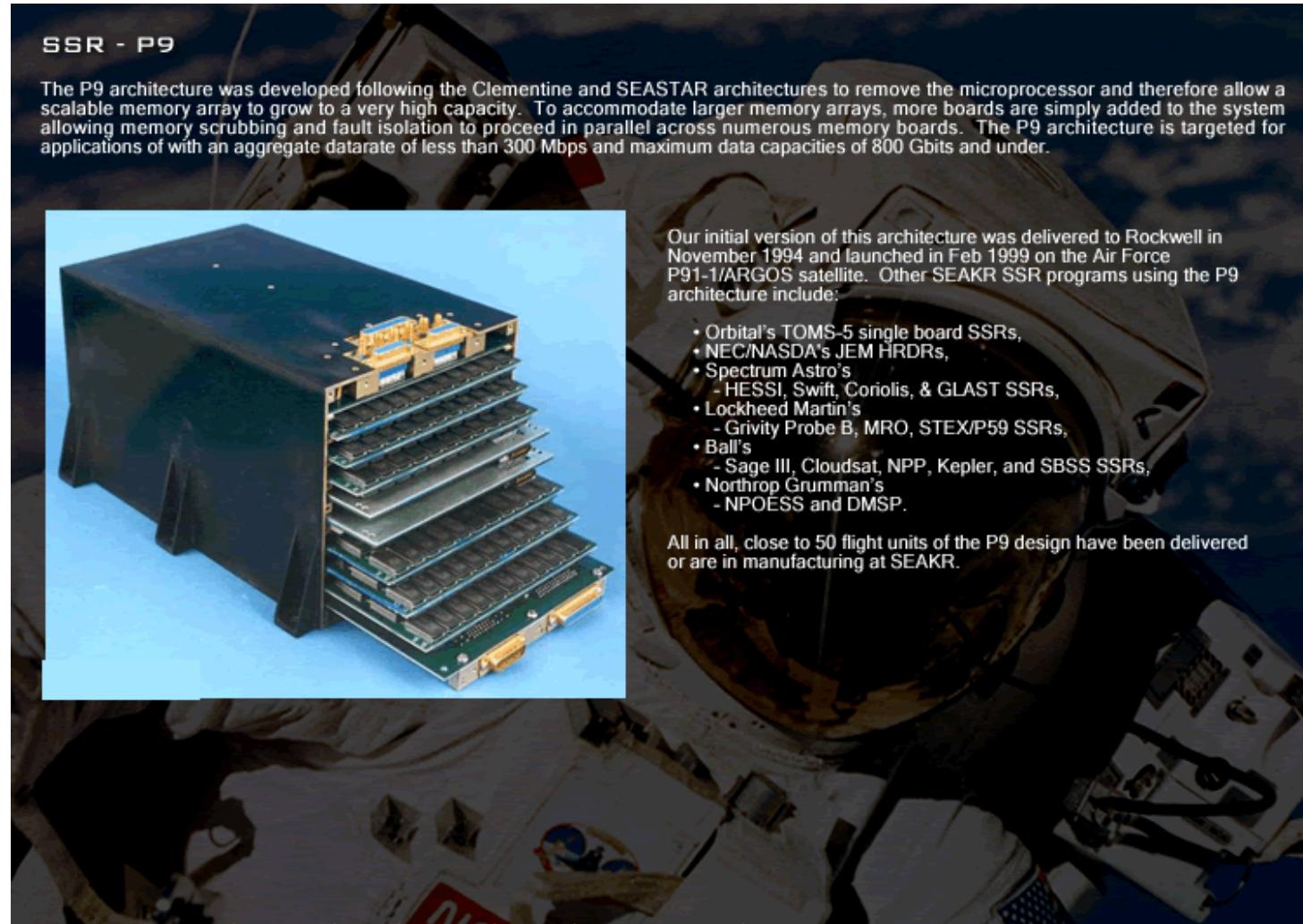
The P9 architecture was developed following the Clementine and SEASTAR architectures to remove the microprocessor and therefore allow a scalable memory array to grow to a very high capacity. To accommodate larger memory arrays, more boards are simply added to the system allowing memory scrubbing and fault isolation to proceed in parallel across numerous memory boards. The P9 architecture is targeted for applications with an aggregate datarate of less than 300 Mbps and maximum data capacities of 800 Gbits and under.



Our initial version of this architecture was delivered to Rockwell in November 1994 and launched in Feb 1999 on the Air Force P91-1/ARGOS satellite. Other SEAKR SSR programs using the P9 architecture include:

- Orbital's TOMS-5 single board SSRs,
- NEC/NASDA's JEM HRDRs,
- Spectrum Astro's
 - HESSI, Swift, Coriolis, & GLAST SSRs,
- Lockheed Martin's
 - Gravitiy Probe B, MRO, STEX/P59 SSRs,
- Ball's
 - Sage III, Cloudsat, NPP, Kepler, and SBSS SSRs,
- Northrop Grumman's
 - NPOESS and DMSP.

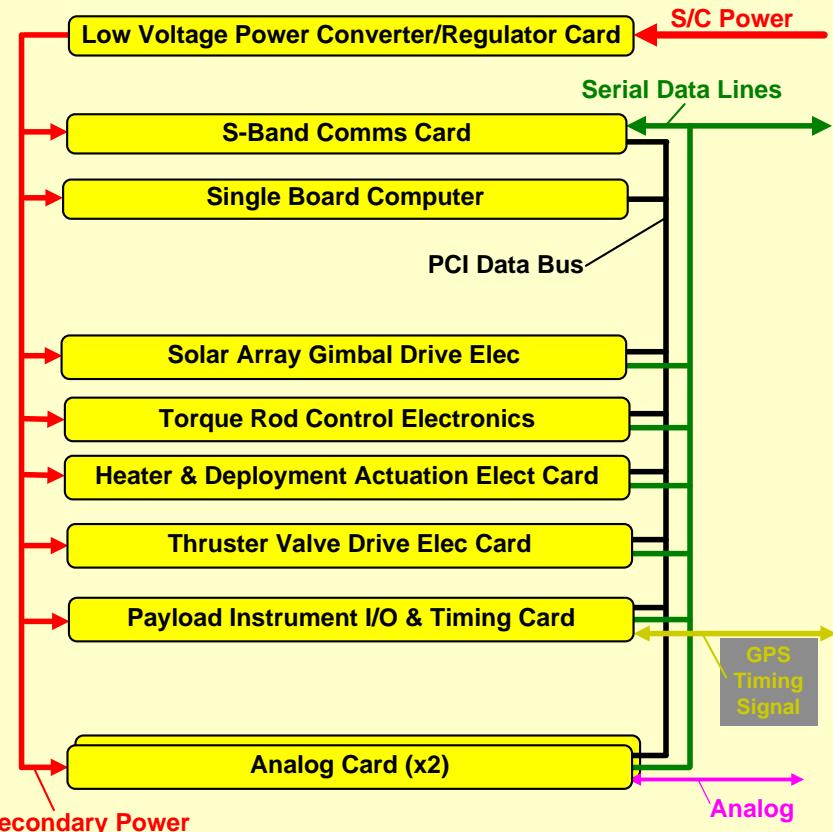
All in all, close to 50 flight units of the P9 design have been delivered or are in manufacturing at SEAKR.



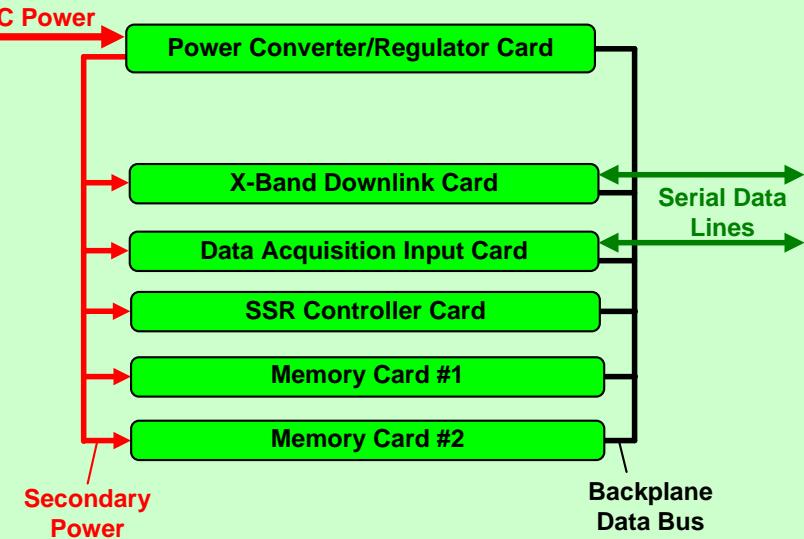
Avionics System Block Diagram Showing Modules and Sub-Modules

M i s s i o n D e s i g n L a b o r a t o r y

Integrated Avionics Unit (IAU)



Solid State Recorder (SSR) (100 Gbit)





Subsystem Description - IAU

M i s s i o n D e s i g n L a b o r a t o r y

Integrated Avionic Unit (IAU)	cards	source	Description
LVPC/Regulator card	1	COTS	Power conditioning and distribution
S-Band Uplink/Downlink card	1	COTS	Ground communications
Rad-750 Single Board Computer card	1	COTS	C&DH and control
Solar Array Gimbal Drive card	1	COTS	Solar Array control
Torquer Rod Control Electronics card	1	COTS	ACS management
Heater & Deployment Actuation Elect card	1	custom	Thermal system control, deployments
Thruster Valve Drive Elect card	1	COTS	Propulsion
Payload Instrument I/O & Timing card	1	custom	Digital I/O, Safehold, GPS/timing signals
Analog card	2	custom	Analog I/O (actual number TBD)
Backplane	1	COTS	Single backplane
Chasis	1	COTS	Standard





Subsystem Description - SSR

M i s s i o n D e s i g n L a b o r a t o r y

Solid State Recorder (SSR)	1	Internal designed redundancy
Power Converter/Regulator card	1	Power conditioning and distribution
X-Band Downlink card	1	Direct ground high speed communications
Data Acquisition Input card	1	Data I/O
SSR Controller card	1	Controller
Memory Card #1	1	Memory (actual number and configuration TBD)
Memory Card #2	1	Memory
Backplane	1	Per vendor specs
Chasis	1	Standard

All these components should be commercially available (COTS)



Data Acquisition Analysis

M i s s i o n D e s i g n L a b o r a t o r y

- **Baseline**

- Orbit: 98.2 minutes
- Observation time: 47min/orbit
- OCE data rate: 10Mbps
- Polarimeter data rate: 2.2Mbps
- S/C housekeeping: 4kbps
- Science data latency: 180 minutes
- Max X-Band transmission rate: 105Mbps

- **General considerations**

- GPS timing and position data available, to be distributed via dedicated bus
- Safehold scheme/algorithm on a dedicated implementation to account for specific instrument safety/survival requirements
- Maximum downlink data rate limited by current standard high-TRL hardware

- **Baseline Results**

- Need **>45Gbit** of storage per orbit (30% margin & CCSDS included)
- Need **>90Gbit** of storage (2 orbits) to avoid data loss in the event of missing one communication contact

- **Broadcast Option**

- Science data transmission on-the-fly
- Science data rate **~12Mbps**
- No major hardware impact identified to implement this option





Data Acquisition Analysis – 2 orbits storage

M i s s i o n D e s i g n L a b o r a t o r y

Data Acquisition - Broadcast Option		
Data Source or type	Average Raw Data (compressed) Rate (kbps)	Average Raw Data Acquisition Period (minutes)
OCE-2 Science + H/K	10,000	47
Polarimeter Science + H/K	2,200	47
Spacecraft H/K Data	4	99
Total	12,204	

Data Storage - Baseline			
Total Data Volume Per Orbit Before Margin (Gbits)	Data Rate Margin or Contingency (%)	Data Volume Per Orbit with Data Rate Margin & CCSDS (Gbits)	Data Volume Two Orbits with Data Rate Margin (Gbits)
28.2	30%	37.43	74.9
6.2	30%	8.23	16.5
0.024	30%	0.03	0.1
34.5		45.7	91.4

Data Downlink - Baseline	
Downlink Data Rate (Mbps)	Trans—mission Time for Two Orbit Data (minutes)
105	14.5





Avionics System Mass & Power Rack-Up Summary

M i s s i o n D e s i g n L a b o r a t o r y

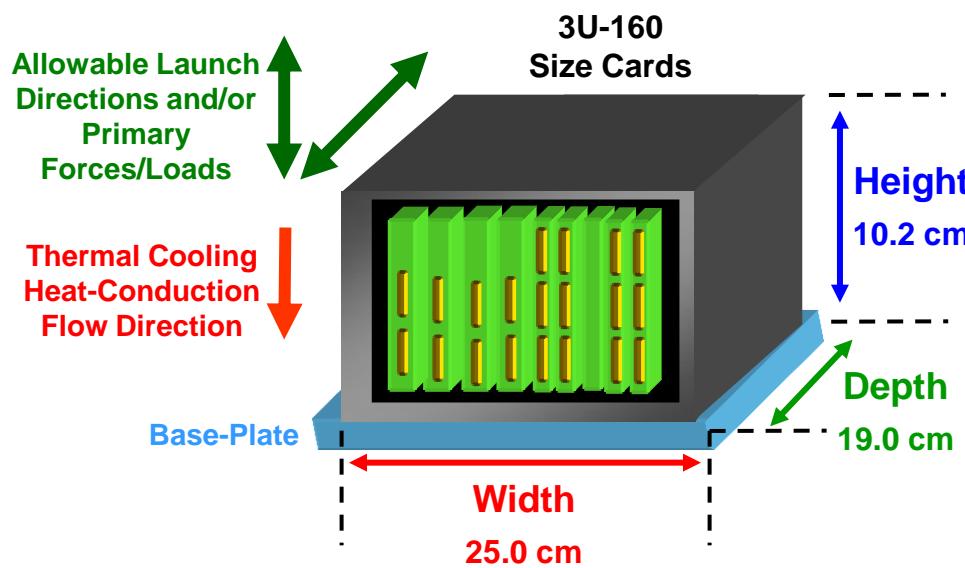
Avionics System - Summary PACE	Number of Units	Total Mass (kg)	Total Power (W, Ops)
Integrated Avionic Unit (IAU)	1	12.1	59.0
Solid State Recorder (SSR)	1	12.1	24.0
Totals	2	24.2	83.0

Note: values on summary chart are nominal mass and power ops.

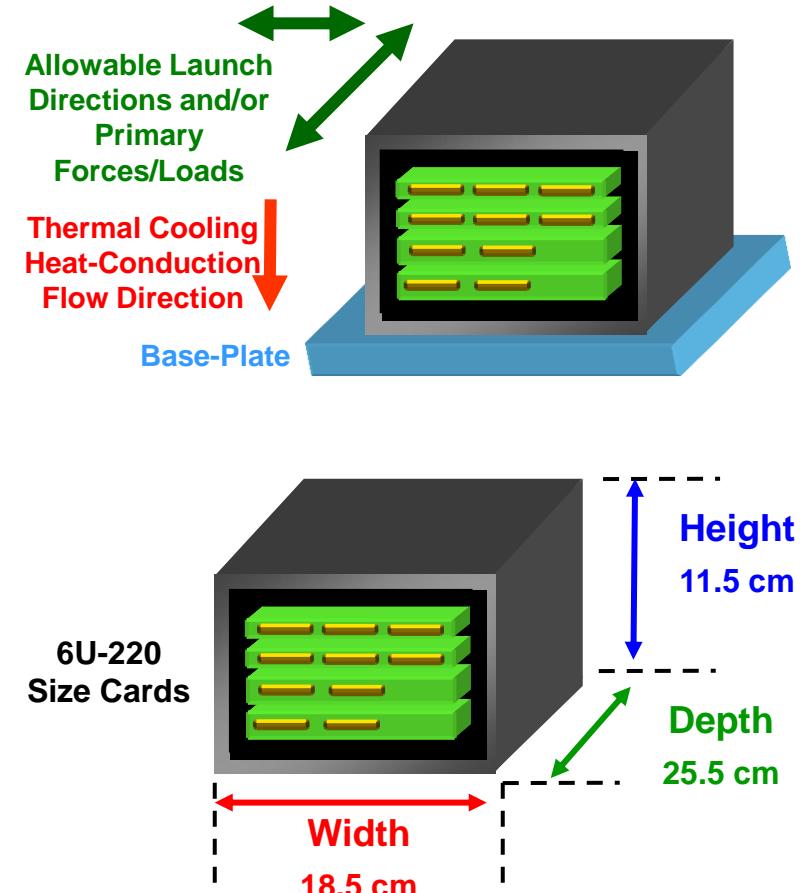


Avionic Unit Physical Configurations, Orientations, and Sizes

M i s s i o n D e s i g n L a b o r a t o r y



Integrated Avionics Unit (IAU)



Solid State Recorder (SSR)



Radiation Effects Analysis

Total Ionizing Dose Effects – 3 years

Total mission dose (rad)									
Al absorber thickness			Total	Trapped electrons	Brems-strahlung	Trapped protons	Solar protons	Tr. electrons+ Bremsstrahlung	Tr. el.+Bremss. +Tr. protons
(mm)	(mils)	(g cm ⁻²)							
0.050	1.968	0.014	1.718E+06	1.672E+06	3.184E+03	3.986E+03	3.820E+04	1.676E+06	1.680E+06
0.100	3.937	0.027	9.452E+05	9.170E+05	1.914E+03	4.001E+03	2.223E+04	9.189E+05	9.229E+05
0.200	7.874	0.054	4.255E+05	4.081E+05	1.008E+03	4.017E+03	1.241E+04	4.091E+05	4.131E+05
0.300	11.811	0.081	2.325E+05	2.192E+05	6.316E+02	4.034E+03	8.579E+03	2.198E+05	2.239E+05
0.400	15.748	0.108	1.445E+05	1.335E+05	4.395E+02	4.054E+03	6.455E+03	1.340E+05	1.380E+05
0.500	19.685	0.135	9.848E+04	8.891E+04	3.313E+02	4.075E+03	5.168E+03	8.924E+04	9.331E+04
0.600	23.622	0.162	7.267E+04	6.397E+04	2.648E+02	4.097E+03	4.336E+03	6.424E+04	6.833E+04
0.800	31.496	0.216	4.743E+04	3.989E+04	1.895E+02	4.144E+03	3.209E+03	4.008E+04	4.422E+04
1.000	39.370	0.270	3.523E+04	2.836E+04	1.488E+02	4.203E+03	2.521E+03	2.850E+04	3.271E+04
1.500	59.055	0.405	2.116E+04	1.509E+04	9.778E+01	4.350E+03	1.628E+03	1.519E+04	1.954E+04
2.000	78.740	0.540	1.518E+04	9.141E+03	7.243E+01	4.801E+03	1.166E+03	9.213E+03	1.401E+04
2.500	98.425	0.675	1.157E+04	5.772E+03	5.708E+01	4.836E+03	8.999E+02	5.829E+03	1.067E+04
3.000	118.110	0.810	9.005E+03	3.691E+03	4.710E+01	4.543E+03	7.236E+02	3.738E+03	8.281E+03
4.000	157.480	1.080	6.267E+03	1.555E+03	3.504E+01	4.172E+03	5.052E+02	1.590E+03	5.762E+03
5.000	196.850	1.350	4.937E+03	6.377E+02	2.800E+01	3.895E+03	3.765E+02	6.657E+02	4.561E+03
6.000	236.220	1.620	4.285E+03	2.467E+02	2.348E+01	3.714E+03	3.010E+02	2.702E+02	3.984E+03
7.000	275.590	1.890	3.928E+03	9.178E+01	2.036E+01	3.571E+03	2.449E+02	1.121E+02	3.683E+03
8.000	314.960	2.160	3.716E+03	3.240E+01	1.807E+01	3.462E+03	2.041E+02	5.046E+01	3.512E+03
9.000	354.330	2.430	3.588E+03	1.084E+01	1.636E+01	3.386E+03	1.748E+02	2.720E+01	3.413E+03
10.000	393.700	2.700	3.482E+03	3.427E+00	1.503E+01	3.314E+03	1.498E+02	1.846E+01	3.332E+03
12.000	472.440	3.240	3.352E+03	2.652E-01	1.307E+01	3.223E+03	1.165E+02	1.333E+01	3.236E+03
14.000	551.180	3.780	3.264E+03	6.734E-03	1.169E+01	3.160E+03	9.258E+01	1.170E+01	3.172E+03
16.000	629.920	4.320	3.212E+03	5.171E-05	1.065E+01	3.126E+03	7.599E+01	1.065E+01	3.136E+03
18.000	708.660	4.860	3.183E+03	5.578E-07	9.779E+00	3.110E+03	6.410E+01	9.779E+00	3.119E+03
20.000	787.400	5.400	3.151E+03	0.000E+00	9.044E+00	3.088E+03	5.411E+01	9.044E+00	3.097E+03





Radiation Effects Analysis

Total Ionizing Dose Effects – 5 years

Total mission dose (rad)									
Al absorber thickness			Total	Trapped electrons	Brems-strahlung	Trapped protons	Solar protons	Tr. electrons+Bremsstrahlung	Tr. el.+Bremss. +Tr. protons
(mm)	(mils)	(g cm ⁻²)							
0.050	1.968	0.014	2.890E+06	2.787E+06	5.306E+03	6.644E+03	9.032E+04	2.793E+06	2.799E+06
0.100	3.937	0.027	1.593E+06	1.528E+06	3.191E+03	6.668E+03	5.443E+04	1.532E+06	1.538E+06
0.200	7.874	0.054	7.206E+05	6.801E+05	1.679E+03	6.695E+03	3.206E+04	6.818E+05	6.885E+05
0.300	11.811	0.081	3.962E+05	3.654E+05	1.053E+03	6.723E+03	2.302E+04	3.664E+05	3.731E+05
0.400	15.748	0.108	2.478E+05	2.226E+05	7.325E+02	6.756E+03	1.780E+04	2.233E+05	2.300E+05
0.500	19.685	0.135	1.701E+05	1.482E+05	5.521E+02	6.791E+03	1.454E+04	1.487E+05	1.555E+05
0.600	23.622	0.162	1.263E+05	1.066E+05	4.414E+02	6.828E+03	1.242E+04	1.071E+05	1.139E+05
0.800	31.496	0.216	8.313E+04	6.648E+04	3.158E+02	6.906E+03	9.422E+03	6.680E+04	7.371E+04
1.000	39.370	0.270	6.205E+04	4.726E+04	2.480E+02	7.005E+03	7.535E+03	4.751E+04	5.451E+04
1.500	59.055	0.405	3.759E+04	2.515E+04	1.630E+02	7.250E+03	5.034E+03	2.531E+04	3.256E+04
2.000	78.740	0.540	2.705E+04	1.523E+04	1.207E+02	8.002E+03	3.689E+03	1.536E+04	2.336E+04
2.500	98.425	0.675	2.067E+04	9.620E+03	9.514E+01	8.060E+03	2.894E+03	9.715E+03	1.778E+04
3.000	118.110	0.810	1.616E+04	6.152E+03	7.850E+01	7.572E+03	2.356E+03	6.230E+03	1.380E+04
4.000	157.480	1.080	1.128E+04	2.591E+03	5.840E+01	6.953E+03	1.676E+03	2.650E+03	9.603E+03
5.000	196.850	1.350	8.867E+03	1.063E+03	4.666E+01	6.492E+03	1.266E+03	1.110E+03	7.601E+03
6.000	236.220	1.620	7.662E+03	4.112E+02	3.914E+01	6.190E+03	1.022E+03	4.503E+02	6.640E+03
7.000	275.590	1.890	6.976E+03	1.530E+02	3.393E+01	5.951E+03	8.386E+02	1.869E+02	6.138E+03
8.000	314.960	2.160	6.557E+03	5.399E+01	3.011E+01	5.769E+03	7.040E+02	8.410E+01	5.853E+03
9.000	354.330	2.430	6.295E+03	1.807E+01	2.726E+01	5.643E+03	6.063E+02	4.533E+01	5.688E+03
10.000	393.700	2.700	6.076E+03	5.711E+00	2.505E+01	5.523E+03	5.223E+02	3.076E+01	5.554E+03
12.000	472.440	3.240	5.803E+03	4.421E-01	2.178E+01	5.371E+03	4.096E+02	2.222E+01	5.393E+03
14.000	551.180	3.780	5.614E+03	1.122E-02	1.949E+01	5.267E+03	3.275E+02	1.950E+01	5.286E+03
16.000	629.920	4.320	5.498E+03	8.618E-05	1.775E+01	5.210E+03	2.703E+02	1.775E+01	5.227E+03
18.000	708.660	4.860	5.428E+03	9.296E-07	1.630E+01	5.183E+03	2.290E+02	1.630E+01	5.199E+03
20.000	787.400	5.400	5.356E+03	0.000E+00	1.507E+01	5.146E+03	1.941E+02	1.507E+01	5.162E+03





Radiation Effects Analysis

Total Ionizing Dose Effects – Conclusions

M I S S I O N D E S I G N L A B O R A T O R Y

- **Mission assumptions:**

- Design for a 3 year mission life with 5 years consumables option.
- The maximum total ionizing dose (TID) for the electronics should not exceed **~50krads** to minimize development costs and to use commercially available build-to-print products.

- **Design assumptions:**

- Standard, off-the-shelf chassis construction provide about **2mm** of Al
- Assume that the surrounding S/C provide **1mm** of “free” shielding
- Assumed effective total shielding built-in: **~3mm** of Aluminum

- **Results:**

- Max TID expected after 3 years: **~9krads (18krads with margin)**
- Max TID expected after 5 years: **~21krads (42krads with margin)**

- **Conclusion:**

- No extra chassis shielding is required if high quality components are used.
- If a 5 years mission (or longer) becomes a firm goal for this project, additional shielding should be considered.



Issues / Potential Risks / Future work

M I S S I O N D E S I G N L A B O R A T O R Y

- **Faster X-Band transmission rate**
 - Previous missions have reported faster X-Band transmission rates (300Mbps)
- **Avionics hardware not considered**
 - Redundancy Management Unit (RMU)
 - Monitor IAU health and initiate RESET to primary or switchover to spare if needed
 - Recommended if a higher redundancy strategy is implemented
 - Adds 3kg mass and 10W power requirements
 - Imply additional hardware redundancy (even more mass & power needed)
- **No major technical risks have been identified at this time**
 - Concept based on conservative assumptions using current TRL understanding



Acronym List

M i s s i o n D e s i g n L a b o r a t o r y

➤ ACS	Attitude Control System	➤ HGA	High Gain Antenna
➤ AI	Aluminum (element)	➤ HK	Housekeeping
➤ BB	Breadboard	➤ IAU	Integrated Avionics Unit
➤ C&DH	Command and Data Handling	➤ kbps	Kilo-bits per second
➤ CDR	Critical Design Review	➤ kg	Kilogram
➤ CDU	COMSEC Decryption Unit	➤ LV	Launch Vehicle
➤ cm	centimeter	➤ Mbps	Mega-bits per second
➤ COMMS	communications	➤ MEL	Master Equipment List
➤ COMSEC	Communications Security	➤ µs	micro-second
➤ COTS	Commercial Off The Shelf	➤ MOC	Mission Operations Center
➤ Cs	Cesium (element)	➤ MW	Momentum Wheel
➤ CsC	Cesium Clock	➤ NSA	National Security Agency
➤ CSS	Coarse Sun Sensor	➤ PSE	Power System Electronics
➤ CCSDS	Consultative Committee for Space Data Systems	➤ RIU	Remote Interface Unit
➤ DEA	Detector Electronics Assembly	➤ RMU	Redundancy Management Unit
➤ DPA	Digital Processing Assembly	➤ ROM	Read-Only Memory
➤ DSN	Deep Space Network	➤ RF	Radio Frequency
➤ DSS	Digital Sun Sensor	➤ RT	Real Time
➤ EDAC	Error Detection and Correction (circuitry)	➤ RW	Reaction Wheel
➤ EOM	End Of Mission	➤ RWA	Reaction Wheel Assembly
➤ ETU	Engineering Test Unit	➤ SA	Solar Array
➤ FEE	Front End Electronics	➤ S/C	Spacecraft
➤ FMA	Flight Mirror Assembly	➤ SDPC	Science Data Processing Center
➤ FSS	Fine Sun Sensor	➤ SOC	Science Operations Center
➤ FSW	Flight Software	➤ SSR	Solid State Recorder
➤ FT	Functional Test	➤ ST	Star Tracker
➤ Gbits	Giga-bits	➤ SUROM	Start-Up ROM (boot program)
➤ Gbps	Giga-bits per second	➤ T&C	Telemetry and Command
➤ GDS	GSFC Dynamics Simulator	➤ TDRSS	Tracking & Data Relay Satellite System
➤ GNC	Guidance, Navigation and Control	➤ TLM	Telemetry
➤ GOTS	Government Off The Shelf	➤ TRL	Technology Readiness Level
➤ GPS	Global Positioning System	➤ W	Watts
➤ GSE	Ground Support [test] Equipment	❖ BRE, Kernco, L3, SEAKR are vendors used as example	
➤ GSFC	Goddard Space Flight Center		





M i s s i o n D e s i g n L a b o r a t o r y

Backup Material





Avionics System Mass Rack-Up - Details

M i s s i o n D e s i g n L a b o r a t o r y

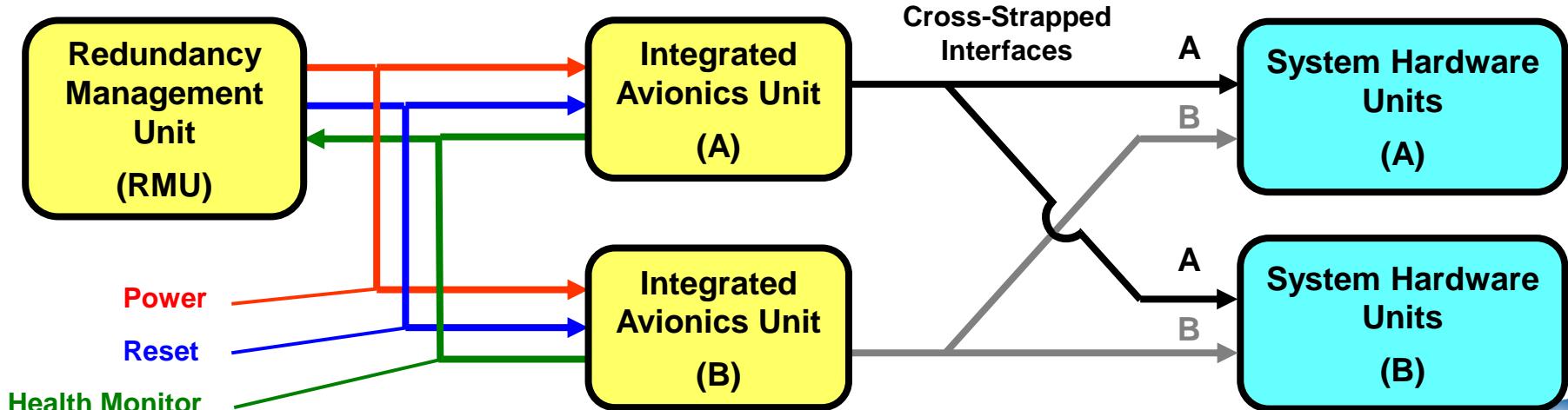
Avionics Suite PACE	Number of units (or cards)	mass/unit (kg)	mass (total)	mass margin	mass total + margin	science ops power (W)	peak power
Integrated Avionic Unit (IAU)	1	11.1	12.1	30%	15.7	59.0	68.0
LVPC/Regulator card	1	1.1	1.1	30%	1.4	20.0	20.0
S-Band Uplink/Downlink card	1	0.9	0.9	30%	1.2	5.0	5.0
Rad-750 Single Board Computer card	1	1.0	1.0	30%	1.3	12.0	12.0
Solar Array Gimbal Drive card	1	1.2	1.2	30%	1.6	3.0	14.0
Torquer Rod Control Electronics card	1	1.1	1.1	30%	1.4	4.0	4.0
Heater & Deployment Actuation Elect card	1	1.0	1.0	30%	1.3	6.0	6.0
Thruster Valve Drive Elect card	1	1.0	1.0	30%	1.3	2.0	0.0
Payload Instrument I/O & Timing card	1	1.0	1.0	30%	1.3	3.0	3.0
Analog card	2	1.0	2.0	30%	2.6	4.0	4.0
Backplane	1	0.3	0.3	30%	0.4	0.0	0.0
Chasis	1	1.5	1.5	30%	2.0	0.0	0.0
Solid State Recorder (SSR)	1	12.1	12.1	30%	15.7	24.0	24.0
Power Converter/Regulator card	1	1.0	1.0	30%	1.3	6.0	6.0
X-Band Downlink card	1	1.0	1.0	30%	1.3	4.0	4.0
Data Acquisition Input card	1	1.0	1.0	30%	1.3	4.0	4.0
SSR Controller card	1	0.8	0.8	30%	1.0	2.0	2.0
Memory Card #1	1	1.5	1.5	30%	2.0	4.0	4.0
Memory Card #2	1	1.5	1.5	30%	2.0	4.0	4.0
Backplane	1	0.3	0.3	30%	0.4	0.0	0.0
Chasis	1	5.0	5.0	30%	6.5	0.0	0.0
Totals (per Unit)	2	23.2	24.2		31.5	83.0	92.0



Fault Tolerance Approach & Description

M I S S I O N D E S I G N L A B O R A T O R Y

- All Electronic Units have the following fault tolerance implementations:
 - Credible single fault tolerant via independent A and B units, or internal redundancy.
 - Cross-Strapped Electrical Interfaces.
 - Spare Units in Cold Standby
- The Integrated Avionics Unit (IAU) requires a special fault tolerant implementation to ensure that the spacecraft always stays power positive and capable of receiving ground commands.
- It uses a Redundancy Management Unit (RMU) to monitor the health of the active IAU and issues a reset or switches to the backup IAU if an unrecoverable fault occurs in the primary IAU.





Avionics Technology – Projections

M i s s i o n D e s i g n L a b o r a t o r y

Avionics Technology Categories	Advancement Projections for Avionics Technology
Avionics Architectures	<ul style="list-style-type: none">Spacecraft spines: Faster, more reliable Power Bus and Data NetworksBackplane spines: Elimination of parallel backplane bussesBetter modularity at subsystem level and card level
Timing	<ul style="list-style-type: none">GPS technology is currently evolving as new satellites come on-line based on Cesium, Rubidium and active maser technology which promise many alternatives in the near future.
Spacecraft Control, Monitoring and Data/Timing Interfaces	<ul style="list-style-type: none">Wireless transmission by thermistors and other sensorsOptical Highly-Robust Data Networks with "T" Connections
Power Switching, Distribution, & Interfaces	<ul style="list-style-type: none">Distributed Power Switching in boxes and/or cards120 VDC Power Distribution
Science Data Acquisition, Processing (Reduction/Compression), Storage and Transmission	<ul style="list-style-type: none">High-Performance Science Data Reduction Processing and CompressionHigh Density, Low-Power, Non-Volatile Data Storage, using Flash Memory chip stacks
Electronic Parts Functionality and Performance	<ul style="list-style-type: none">System-On-A-Chip TechnologyModular, Customizable Parts with simplified interfaces
Electronics Packaging, Densities and Standard Card Sizes	<ul style="list-style-type: none">Density gains and power reductions will probably be offset by increases due to modularity inefficiencies, fault tolerance enhancements, and functional/performance requirements.
Electronics Power Consumption and Dissipation	
Electronics Reliability and Fault Tolerance	<ul style="list-style-type: none">Architectures and interfaces that allow redundancy at lower levels such as cards and parts.
Spacecraft Avionics Cost	<ul style="list-style-type: none">NRE Costs should decrease modestly because of better engineering tools and highly modular, reusable designs.Recurring costs for parts, etc may continue to rise due to inability to use COTS parts in space applications.

